Validation and Research Utilization of the NRL Regional Model for the U.S. West Coast

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LONG-TERM GOALS

Our long-term goal is to understand the spatially and temporally varying circulation in the California Current System. One aspect of the circulation is a quantitative description of the spatial and temporal variability of currents and water properties, including the time-varying mean fields and their higher order statistics. Another aspect is the quantification of the momentum and heat balances that govern that variability.

OBJECTIVES

In this project, we are examining output from the regional numerical circulation model in use by the U.S. Navy at NRL, as applied to the circulation of the California Current.

Our specific objectives are:
(1) To determine how well the regional nested NRL model reproduces the features and statistical fields as observed by satellite data and field surveys (the seasonal development of 2-D spatial structure of surface velocity and eddy statistics, the seasonal development of the 3-D circulation, Lagrangian eddy statistics, etc.).
(2) To use the model, in combination with the satellite and field data, to understand the processes that control transports in the large-scale eastern boundary current and the more detailed circulation over the shelf and slope; and
(3) To develop the methodology for nesting high-resolution models of circulation over the west coast

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continental shelf and slope within the Navy regional model, to test the nested models by comparison with observations, and to use the nested models to study the dynamics of wintertime shelf circulation processes on the Northern California coast.

APPROACH

Navy modelers at NRL are developing and using a regional, coastal ocean circulation model that can be implemented in any part of the global ocean, nested within the Navy's global ocean circulation model. They are presently testing the regional model in the California Current System (CCS) along the U.S. west coast from 30°N—50°N, using wind forcing from the U.S. Navy atmospheric model from July 1993 through 1997. This model (and its successors) will be used over the next five years in the CCS region under an internal NRL ARI with John Kindle as PI, including ecosystem and optical submodels.

Our general approach is to evaluate the realism of the NRL regional model by comparing statistical and dynamic analyses of the model output fields to identical analyses of satellite and in situ fields from the same regions and periods.

To investigate very high-resolution nested models, we conduct modeling studies of coastal circulation off Northern California in the vicinity of the Eel River (40.75 N - the site of the ONR-sponsored STRATAFORM observational program). We use a series of nested hydrostatic, primitive equation models in order to simulate coastal flow on a high-resolution grid of a limited area. For the nested simulations, the outer model is the NRL regional model of the NE Pacific Ocean with approximately 9 km resolution. Nests of approximately 3 km and 1 km grid spacing are used, with high resolution bathymetry and coastline and realistic river run-off. We simulate the shelf and slope flow surrounding Cape Mendocino during the winter of 1996-1997, during which period intense wind and buoyancy forcing characterized the Cape Mendocino area. The validity of the model simulations is assessed by comparison with measurements from the STRATAFORM program.

WORK COMPLETED

Statistical analyses of the altimeter and SST data are in press [Strub and James, 1999]. Several evaluations of the in situ data have also been completed [Shearman et al. 1999a, 1999b, 1999c]. The POM/PWC model has been run from June 1993 though the end of 1997. We have calculated mean and eddy kinetic fields from model velocities and sea surface heights. These fields and their seasonal development have been compared to satellite altimeter data. To compare the trajectories of drifters in the region we seeded the model with clusters of simulated surface drifters. Drifter trajectories, and velocity and vorticity along the trajectories have been analyzed and compared to real drifters.

Two one-way nested grid models have been configured and simulated within the NRL model. The first nested grid extends approximately 200 km offshore and 475 km alongshore and has about 3 km resolution. This nested model was run for over 100 days during winter 1996-1997. The second nested grid is located within the domain of the first nested grid and extends about 125 km offshore and 275 km alongshore and has about 1 km resolution. This second nested grid model was simulated for 40 days - focused on the Eel River 80 year flood event that occurred in early January 1997.

Both time evolution and statistical properties of the model flow fields have been compared with those

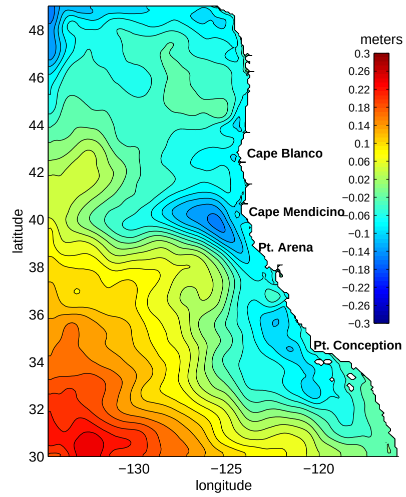

Figure 1. POM/PWC mean SSH (1994-1997). CI=2cm.

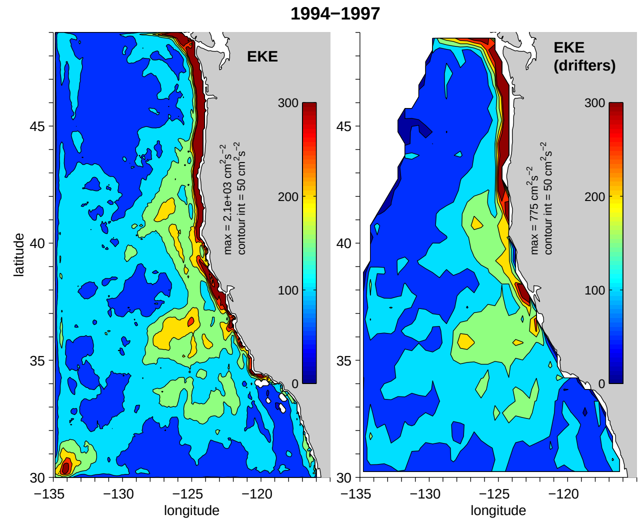

Figure 2. Model EKE fields from the gridded model surface velocities (left) and binned (1/2 deg) drifters (right).

of the STRATAFORM observations. The spatial variability of the first nested model winter currents has been characterized statistically. The alongshore structure of the Eel River plume on the second nested model was investigated.

RESULTS

Strub and James [1999] describe the California Current System using data from the TOPEX, ERS-1, and Geosat satellite altimeters. Equatorward alongshore winds force the development of an equatorward jet in the spring and summer near the coast. As the jet strengthens through the fall season, it moves offshore and develops strong meanders and closed eddies. Satellite eddy kinetic energy estimates show the corresponding offshore movement of high energy and its input into the Pacific interior. Near-surface drifters deployed in the California Current System show regions of high eddy kinetic energy near the coast which decrease offshore and to the south. Seasonal analysis of the drifter data suggests an offshore movement of the EKE similar to the altimeter results [Kelly et al., 1998].

The seasonal development of the POM/PWC model SSH is qualitatively similiar. Two month means computed from the the 1994-1997 model time period show a a winter SSH high next to the coast that is pushed offshore in March/April by the low SSH upwelling signal next to the coast. The low expands offshore in spring-summer and separates from the coast in July/August, moving farther offshore as a nearshore high begins to develop at the coast. In comparison to the similar 2-month mean SSHs from TOPEX, the model features separate more quickly from the coast and lead the altimeter data by almost 2 months.

The 4-year (1994-1997) mean model SSH field is shown in Fig. 1. In general, the SSH contours show slow, south-eastward moving flow, as expected. One of the strongest features, however, is a strong offshore-onshore meander near Cape Mendocino (39-41N). Note also the onshore-offshore flow north and south of Monterey Bay (36-37N). This feature is not apparent in dynamic heights calculated from climatological temperature and salinity fields [Levitus and Gelfeld, 1992], nor in the mean height field constructed by Kelly et al. [1998]. Likewise the onshore/offshore flow, north/south of Monterey Bay, does not appear in the fields of Kelly et. al., or the more well-sampled CalCOFI dynamic height fields of Lynn and Simpson [1987]. A comparison with the depth contours suggests that this flow is strongly linked to the bottom topography of the Mendicino Ridge [Righi et al., 1999].

The effect of the strong onshore flow at 39N can also be seen in the eddy kinetic energy fields from the model velocities and simulated drifters (Figure 2). Both fields show regions of high variability close to shore from 35-43N, and in offshore regions north of Cape Mendocino and south of San Francisco. Offshore at 38N there is a strong low in EKE. In contrast, TOPEX EKE fields have a high in EKE centered at 38N, 127W. We believe that overly strong topographic steering causes the model velocity fields to take a semipermanent path in this region that confines most of the kinetic energy to the mean, limiting the energy in the eddy field.

Besides comparisons to the altimeter data, the model surface current fields were used to advect clusters of drifters. The paths of these clusters were used to derive the vorticity along the path of the cluster, using the methods of Okubo and Ebbesmeyer [1976], a preliminary step in calculating vertical velocities. Comparison to values of vorticity from the model fields allowed improved tests of the reliability of the method, as presented by Righi and Strub [1999].

On smaller scales, the results of Shearman et al. [1999a, 1999b, 1999c] provide a characterization of the vertical velocity fields associated with mesoscale features. These can be compared to similar model fields. In addition, Shearman et al. identify two types of eddies in the California Current - the surface cyclonic eddies associated with meanders in the jet and the deep anticyclonic eddies that may be associated with the undercurrent. Realistic model fields should produce similar structures.

Finally, the nested models (3 km and 1 km grids) have been successfully used to improve the velocity fields of the 9 km NRL model. Using the same model wind forcing (Figure 3, top) as in the NRL model, the 3 km resolution model exhibits many features of the observed strongly wind-forced shelf flow regime. Good agreement is found between the amplitude and time variability of the 3 km model currents and the observed currents on the shelf at 50m depth (Figure 3, bottom). By contrast, the coarser 9 km resolution NRL U.S. West Coast Model does not as accurately capture the observed flow variability at the shelf mooring site Figure 3, middle). The 1 km resolution model provides increased resolution of the interaction between the shelf flow and the Eel River plume, which has significant alongshore variability as it progesses up the coast.

IMPACT/APPLICATIONS

The Navy is developing this relocatable regional model for global operational use. The same model is planned to be used as NOAA’s operational coastal ocean forecast model off the west coast. Fields from the model will be used by the Coast Guard for search and rescue efforts, by fisheries managers, and many others, including academic researchers. Given this level of use for the model output fields, it is vital to quantify the errors in the model fields, so that model fields can be better interpreted.

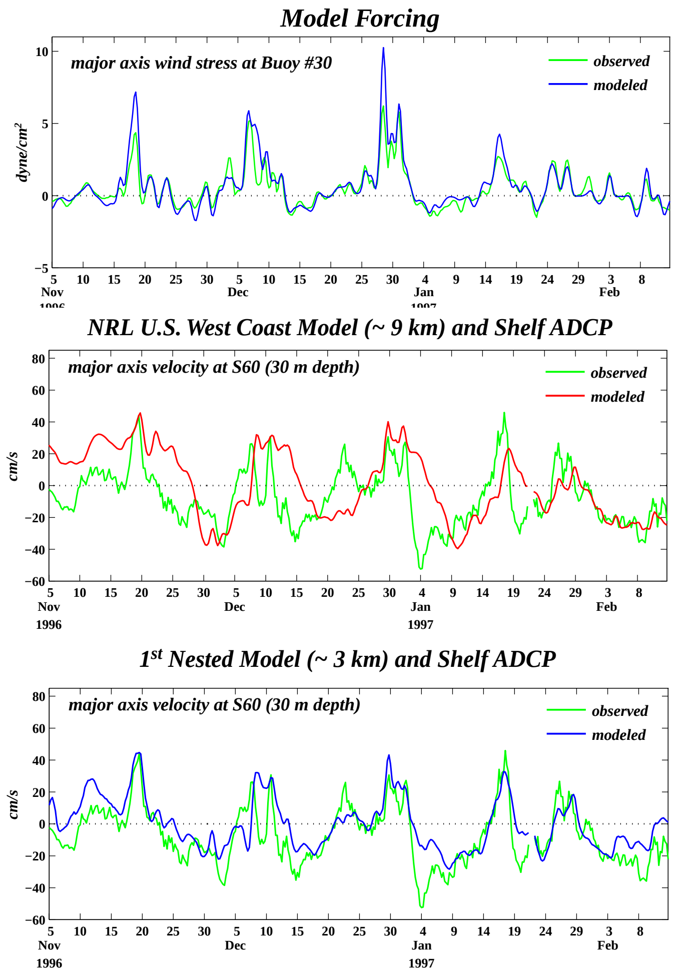

Figure 3. Model and measured wind forcing (top) . Measured 30m velocity over the shelf (50m depth) compared to the NRL 9 km model (middle) and the intermediate (3 km) nested model (bottom).

TRANSITIONS

The model will be used operationally by many several agencies. The results from our validation efforts will provide estimates of model uncertainty.

RELATED PROJECTS

1. John Kindle and coworkers are using the NRL regional model as the basis for ecosystem models and optical models at NRL.
2. A similar model evaluation using altimeter data may be proposed as part of a West Coast NOPP proposal under discussion, testing a variety of models.
3. Results of this study will be communicated to those modeling and observing the California Current in the US GLOBEC North-East Pacific study, in which Strub and Barth are PI's.
4. John Allen is conducting high resolution modeling of the shelf region in the northern California Current region within CoOP and NOPP projects (in collaboration with GLOBEC modelers).

REFERENCES

Blumberg, A. F., and G. L. Mellor, A description of a three-dimensional coastal circulation model, in *Three-Dimensional Coastal Models*, edited by N. Heaps, American Geophysical Union, 1997.

Clancy, R. M., P. W. deWitt, P. May, and D. S. Ko, Implementation of a coastal ocean circulation model for the west coast of the United States, in *Conference on Coastal Oceanic and Atmospheric Prediction, Jan. 28 - Feb. 2, 1996, Atlanta, GA*, pp. 72-75, American Meteorological Society, 1996.

Kelly, K. A., R. C. Beardsley, R. Limeburner, K. H. Brink, J. D. Paduan, and T. K. Chereskin, Variability of the near-surface eddy kinetic energy in the California Current based on altimetric, drifter and moored current data, *J. Geophys. Res., 103*, 13,067-13,083, 1998.

Levitus, S., and R. Gelfeld, NODC inventory of physical oceanographic profiles, in *Key to Oceanography Records Documentation, No. 18*, U.S. gov. Printing Office, 1992.

Lynn, R. S., and J. J. Simpson, The California Current System: The seasonal variability of its physical characteristics, *J. Geophys. Res., 92*, 12,947-12,966, 1987.

Okubo, A., and C. C. Ebbesmeyer, Determination of vorticity, divergence and deformation rates from analysis of drogue observations, *Deep-Sea Res., 23*, 349-352, 1976.

Shearman, R. K., J. A. Barth, and P.M. Kosro, 1999a. Diagnosis of the three-dimensional circulation associated with mesoscale motion in the California Current. *J. Phys. Oceanogr. , 29*, 651-670.

Shearman, R. K., J. A. Barth, J. S. Allen, and R. L. Haney, 1999b. Diagnosis of the three-dimensional circulation in mesoscale features with large Rossby number. *J. Phys. Oceanogr.*, (in revision).

Shearman, R.K., J.A. Barth, A. Huyer, P.M. Kosro, and R.L. Smith, 1999c. Evolution of mesoscale features in the California Current. *J. Geophys. Res.* (submitted).

Strub, P.T., and C. James, 1999. Altimeter-derived variability of surface velocities in the California Current System: 2. Seasonal circulation and eddy statistics. *Deep-Sea Res. II* (in press).

PUBLICATIONS

Righi, D. D., and P. T. Strub, 1999. The use of simulated drifters to estimate vorticity, *J. Mar. Sys.* (submitted).

Righi, D. D., P. T. Strub, and J. Kindle, 1999. Validation of a California Current model through comparison with altimeter and drifter circulation statistics, *Preprint Volume, Third Conference on Coastal Atmospheric and Oceanic Prediction and Processes, November 1999*, American Meteorology Society.

Shearman, R. K., J. A. Barth, and P.M. Kosro, 1999a. Diagnosis of the three-dimensional circulation associated with mesoscale motion in the California Current. *J. Phys. Oceanogr. , 29*, 651-670.

Shearman, R. K., J. A. Barth, J. S. Allen, and R. L. Haney, 1999b. Diagnosis of the three-dimensional circulation in mesoscale features with large Rossby number. *J. Phys. Oceanogr.*, (in revision).

Shearman, R.K., J.A. Barth, A. Huyer, P.M. Kosro, and R.L. Smith, 1999c. Evolution of mesoscale features in the California Current. *J. Geophys. Res.* (submitted).

Strub, P.T., and C. James, 1999. Altimeter-derived variability of surface velocities in the California Current System: 2. Seasonal circulation and eddy statistics. *Deep-Sea Res. II* (in press).